As the results of these experiments seem to justify very completely the use of Callendar's parabolic formula over a wide range, a table has been calculated by which the value of T may be obtained directly from the value of P*t* for a range of temperature extending from -200 to $+1100^{\circ}$ C., and for the value 1·5 of the constant δ.

A second short table extends this to all values of δ usually met with. It is hoped that this table may be of general use to others who are employing platinum thermometers.

The experiments were carried out at the National Physical Laboratory, and, in conclusion, I wish to thank those members of the staff who have assisted in it.

"The Spectra of Antarian Stars in Relation to the Fluted Spectrum of Titanium." By A. FOWLER, A.R.C.S., F.R.A.S., Assistant Professor of Physics at the Royal College of Science, South Kensington. Communicated by Professor H. L. CALLENDAR, F.R.S. Received February 18,—Read March 3, 1904.

[PLATE 6.]

The distinguishing feature of the spectra of the Antarian Stars* is the system of apparently dark flutings, sharp towards the violet and fading off towards the red end of the spectrum. The principal flutings are well seen in Antares, but they are more strongly developed in the spectra of α Herculis and o Ceti, in which stars additional details are also seen. These flutings have not hitherto received a definite chemical interpretation, and it has been uncertain, owing to the possibly misleading effects of contrast, whether the spectrum was to be regarded as one consisting wholly of absorption flutings fading towards the red, or as one partly consisting of emission flutings fading in the opposite direction.

The purpose of the present communication is to state the nature of the evidence which indicates that the spectrum is essentially an absorption spectrum, and that the chief substance concerned in the production of the flutings is titanium, or possibly a compound of that element with oxygen.

The first indication of this result was the striking general resemblance of the titanium flutings, as seen in photographs recently obtained, with the stellar flutings, both as to relative intensity and apparent position (Plate 6). The interspaces between the flutings, as they appear on a negative, in some cases also strongly recall the corresponding bright spaces in the stellar spectra.

* Secchi's Type III; Vogel's Class III*a*.

The most extensive series of visual observations of the Antarian stars were made by Vogel* and Dunér† many years ago, and for the part of the spectrum extending from near D to the extreme red, no other measurements have yet been published. For the region more refrangible than D, however, wave-lengths derived from photographs are available, the most complete statements of these being due to Father Sidgreaves‡ and Mr. Stebbings.§ The individual results given by different observers vary considerably: visual observations are difficult, and, in the case of photographs taken with prismatic cameras, errors doubtless arise through the lack of suitable reference lines. There is also some difficulty in deciding where a fluting actually commences. The evidence in favour of a titanium origin for most of the flutings, however, depends on such a large number of coincidences that it is almost independent of a very precise knowledge of wave-lengths.

The flutings in question come out in the arc spectrum of titanium oxide, if the precaution be taken to provide a liberal supply of material and to use a very long arc, taking care also that the image of the "flame" is projected on the slit of the spectroscope. They are also seen in the arc spectrum of the chloride under similar conditions. Numerous lines accompany the flutings produced in this manner and some of the details are consequently masked or not recognized without careful study of the photographs.

So far the flutings have not been very successfully produced in the oxyhydrogen flame; they are visible in the flame spectrum of the fumes from the chloride, but their observation is difficult on account of the bright continuous spectrum.

The best representation of the flutings has been obtained by passing a spark, without jar, through the fumes of oxychloride which rise from the chloride of titanium on exposure to air. Under these circumstances the lines which appear are not numerous, and some of the secondary flutings which are masked by lines in the spectrum of the flame of the arc are readily detected, in spite of the continuous spectrum which is also present. The few lines which do appear in this spectrum are probably low temperature lines which may be found of special importance in the cooler stars.

Photographs have been taken over the region C to K, the instrument employed being one built up on the Littrow principle, having one prism of 60°,‖ and a 2-inch objective of 40 inches focal length, giving a linear dispersion from D to K of 5 inches. Wave-lengths were

* 'Beobachtungen zu Bothkamp,' vol. 1, p. 20, etc.

† 'Sur les Etoiles à Spectres de la Troisième Classe'; "K. Sven. Vet.-Akad. Hand.," vol. 21, No. 2, 1884.

‡ 'Monthly Notices, R.A.S.,' vol. 58, p. 344; vol. 59, p. 509.

§ 'Lick Observatory Circular,' No. 41, May, 1903.

‖ Lent by the Government Grant Committee.

determined in the usual manner by micrometric measurements of the photographs, using reference lines of titanium and iron, and calculating by the Cornu-Hartmann formula; though only provisional, they are probably not greatly in error.

It is instructive first to make a comparison between the more conspicuous flutings and those recorded visually in the stars by Vogel and Dunér. Details of the measurements are given in Table I, but reference should also be made to Plate 6, in which Dunér's drawing of the spectrum of α Herculis, as seen with a spectroscope of small dispersion, is compared with a negative of the titanium flutings, as they appear in the "arc" spectrum of titanium oxide.

Table I.—Comparison of Titanium Flutings with Visual Observations of the Spectra of Antarian Stars.

Titanium flutings.		Antarian flutings (more refrangible edge).	
Wave-length.	Visual intensity.	Wave-length.*	Dunér's number.
7055	10	..	Out of range.
..	..	6493	1
6162·5	10	6164	2
..	..	5862	3
5604·5	8	5596	4
5447·0	10	5453	5
5241·0	5	5243	6
5167·5	10	5169	7
4955·1	8	4960	8
4761·6	7	4769	9
4584·3	5	4608	10

It will be seen be seen that eight of the ten bands recorded by Vogel and Dunér agree within the possible limits of error with the flutings of titanium, and it is to be noted also that the only one of the principal titanium flutings which is not represented in the stellar spectrum is out of range in the extreme red. The origin of the two outstanding bands at 5862 and 6493 has not yet been ascertained. There are traces of titanium flutings near their positions, but they seem inadequate to account for two such distinct bands as those drawn

* The wave-lengths given are the means of Vogel's and Dunér's measurements, corrected to Rowland's scale (Scheiner's 'Astronomical Spectroscopy,' p. 301). For bands 5, 7, 8, 9, 10, the means of the wave-lengths derived from photographs by Lockyer, Pickering, Sidgreaves and Stebbings are respectively 5448, 5165, 4954 4761, and 4584 (see Table II).

Table II.—Comparison of Titanium Flutings with Photographic Spectra of Antarian Stars.

Flutings of Ti (Fowler).*		Flutings in stars (Stebbings).		Flutings in *o* Ceti (Sidgreaves).		Remarks.
λ.	Intensity.	λ mean of five stars.†	*o* Ceti.	λ.	Intensity.	
			4313·4			
4352·9	3	..	4352·7	4352	7	
4395·2	3	..	4395·0	4395	5	Masked by lines in arc spectrum.
4422·0	2	4421·5	4421·5	4421	4	" " "
4437·0	3	..	..	..	..	Masked in arc spectrum. Sidgreaves notes a "wide line" at 4436.
4461·9	4	..	4462·1	4460	6	Head well defined.
4505·0	4	..	4504·8	4504	6	Head not very well defined. Not recognised in arc spectrum.
4548·4	3	..	4547·9	4546	5	Head apparently strengthened by a line at 4548·9.
4584·3	6	4584·4	4584·1	4583	10	Beginning of Dunér's band 10, λ 4585 Lockyer,‡ 4586 Pickering.§ Head has the appearance of a double line.
4626·4	6	4626·3	4625·8	4625	8	Head well defined, and has the appearance of a double line.
4667·8	5	4667·6	4668·6	4669	9	" " " " " "
4714·5	3	4714·1	4713·2	4714	4	Head not sharply defined.
4738·0	2	4737·1	..	4736	3	Possibly only an ill-defined line which appears in "chloride" spark, but not in the arc.
4761·6	7	4761·0	4759·0	4758	10	Beginning of Dunér's band 9, λ 4763 Lockyer, 4762 Pickering. Head sharply defined, and has the appearance of a double line.
4805·6	7	4804·6	4803·2	4803	6	Head appears as a double line.
4842·0	1	..	4841·8	4842	8	A feeble brightening seen only in best photographs; it is not the Ti line λ 4841·0.
4848·6	5	4848·4	..	..	..	Head appears as a double line.
4894·0	2	..	..	4892	3	Head indefinite.

4955·1	8	4954·5	4953·1	4951	10	Beginning of Dunér's band 8, λ 4958 Lockyer, 4954 Pickering. Head sharply defined; a line at 4957·8 possibly forming part of a double head.
5002·8	4	..	..	4998	9	Head rather indefinite; not clearly distinguished in arc. Lines at 4981·9, 4991·2, 4999·7, 5007·4, 5014·4.
5050·5	2	..	..	5046	6	Head rather indefinite; not clearly distinguished in arc.
				5074	3	
				5098	4	
				5135	3	
5167·5	10	5165·8	5165·9	5162	10	Beginning of Dunér's band 7, λ 5165 Lockyer, 5168 Pickering. Head very sharply defined and perhaps double with 2nd head at 5169·8.
5241·0	5	..	..	5237	8	Beginning of Dunér's band 6. Begins with a line which is relatively stronger than in the arc spectrum.
5308·0	3	..	5307·2	5306	7	
5356·6	4	..	5357·7	5356	6	
5407·0	1	..	..	5406	2	
			5438·3			
5447·0	10	5446·8	5446·8	5447	10	Beginning of Dunér's band 5, λ 5455 Lockyer, 5445 Pickering. Head very sharply defined.
5497·5	5	5496·8	5496·9	5498	5	Head well defined.
5604·5	8	..	..	5597	8	Beginning of Dunér's band 4. There are strong lines near 5598, 5630, 5662, 5708, which, with small dispersion, might appear to be the heads of the adjacent flutings. Among other details within this group, Sidgreaves notes "bands" at 5603 and 5642, and a "wide line" at 5667.
5636·3	6					
5668·4	5	..	..	5660	7	
5713·9	3	..	..	5709	3	
5760·9	5	..	..	5756	8	Head well defined } Among the details in this region Sidgreaves notes "bands" at 5761, 5808, and 5845.
5811·0	5	..	..	5804	8	,, ,,
5847·2	3	..	..	5840	8	,, ,,

* As seen in spark without jar through fumes from titanium chloride; they are also seen in the arc unless otherwise stated.

† α Herculis, ρ Persei, β Pegasi, α Orionis, α Ceti.

‡ 'Phil. Trans.,' A, vol. 186, 1893, p. 702.

§ 'Annals Harv. Coll. Obs.,' vol. 28 Part 1, p. 8.

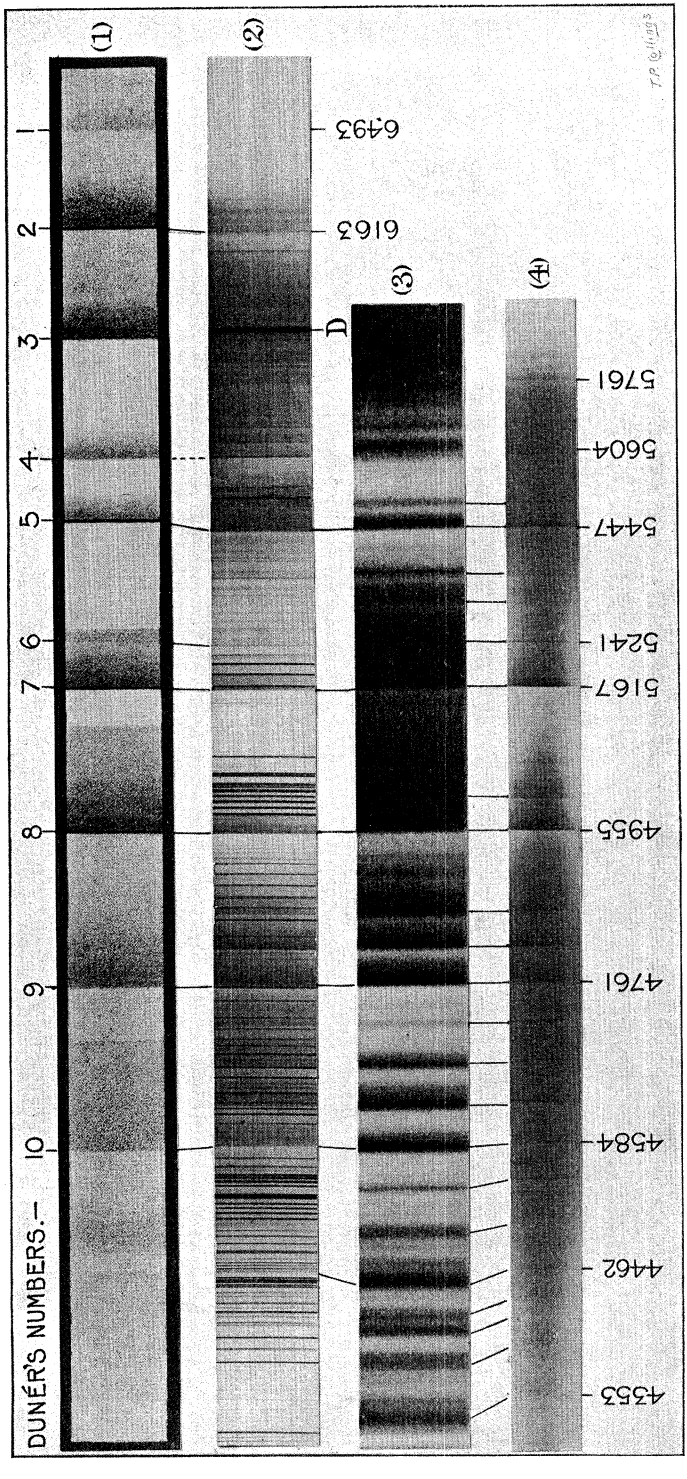
by Dunér. The association of vanadium with titanium in the spectra of sun spots suggested that they might be due to the former element, but this does not appear to be the case. The strongest fluting of vanadium is near 5472, and there is no certain evidence to show the presence of this fluting in the Antarian type of spectrum.

The evidence for titanium in the case of the remaining flutings, however, is enormously strengthened by a discussion of their structure and by extending the comparison further into the violet. Photographs of the stellar spectra, especially those of *o* Ceti and *α* Herculis, show that some of the principal flutings are composite, Dunér's band 10, for example, containing, according to Sidgreaves, four distinct flutings separated by intervals of about 44 tenth-metres, each of which is weaker than the one which precedes it on the more refrangible side. A precisely similar structure is found in the case of the titanium flutings, and a comparison of wave-lengths indicates that the various components occupy the same positions as those in the stars, so far as the available measurements permit the test to be applied. For this comparison (Table II) the wave-lengths derived from photographs by Father Sidgreaves and Mr. Stebbings are utilised. The relation may also be gathered by inspection of the reproductions of the photographs given in Plate 6, that of *o* Ceti having been very kindly placed at my disposal by Father Sidgreaves. Not all the details of the negatives, however, can be brought out in the reproductions, and the relative dispersions are not exactly the same.

It will be seen from the table that the details of the titanium flutings are reproduced with remarkable fidelity in the stellar spectra, and more especially in *o* Ceti. In the latter spectrum the number of flutings recorded is slightly greater than in the case of titanium, but it is by no means certain that every detail of the titanium spectrum has yet been photographed. It is possible also that some of the features described as flutings in the stellar spectrum may be groups of lines, and in at least one instance (4437) a fluting has been classed as a "wide line."

The points of difference are very slight, and are mostly in the less refrangible part of the spectrum, where the reductions of the stellar spectra present the greatest difficulty. There is a peculiar displacement of the fluting 4848 to λ 4842 in the spectrum of *o* Ceti, which may possibly be due to the superposition of a fluting or group of lines of undetermined origin; or, it may be that the feeble maximum observed at 4842 in titanium is strong enough in this spectrum to account for the apparent shift. There is also some uncertainty in connection with the complicated groups of flutings and lines extending from 5598 to D, which need further investigation in the stellar spectra with instruments of greater dispersion.

The general agreement is nevertheless such as to leave no reason-



(1) α Herculis (Dunér), (2) Titanium in flame of arc.
(3) ο Ceti (Stonyhurst), (4) Titanium in spark without jar.

able doubt that titanium is the main factor in the production of the dark flutings which characterise the Antarian group of stars.

This explanation of the dark flutings suggests that the appearance of bright flutings in the Antarian spectrum arises chiefly from effects of contrast. It does not, of course, exclude the possibility of the presence of bright flutings, such as might be indicated by local brightenings which are not exactly in coincidence with the edges of dark flutings.

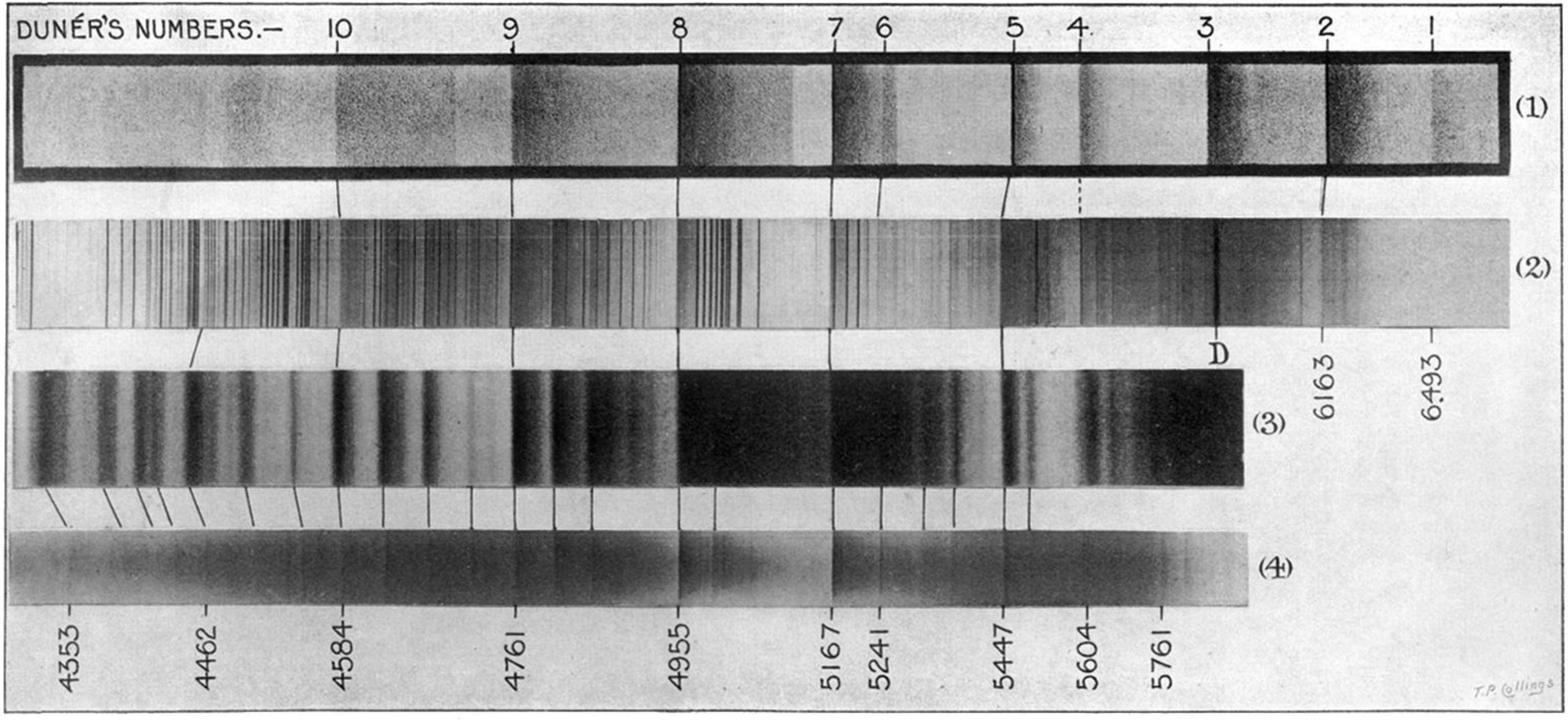
Whether the absorption flutings are produced by the vapour of titanium or by that of the oxide has not yet been completely determined. As already pointed out, the flutings may be obtained either from the oxide or the chloride, but as the latter so readily unites with oxygen on exposure to air, it furnishes no evidence against the supposition that the flutings are due to the oxide.

The author has pleasure in acknowledging the very able assistance which has been rendered in the experimental work involved in this investigation by Mr. F. W. Jordan, B.Sc., Teacher in Training in the Department of Astronomical Physics, Royal College of Science.

DESCRIPTION OF PLATE 6.

1. Visible spectrum of α Herculis, as drawn by Dunér.
2. Flutings of titanium, as they appear in the spectrum of the "flame of the arc," when charged with titanium oxide.
3. Photographic spectrum of o Ceti, from a photograph taken at the Stonyhurst College Observatory, November 29, 1897.
4. Flutings of titanium, as they appear when a spark, without jar, is passed through the fumes which rise from titanium chloride on exposure to air.

(*Note.*—The coincidences cannot be very exactly shown in this manner, on account of the differences of dispersion of the three instruments with which the spectra were recorded.)



(1) α Herculis (Dunér).
(2) Titanium in flame of arc.
(3) ο Ceti (Stonyhurst).
(4) Titanium in spark without jar.